# Chang' e-3 Mission and Its Preliminary Scientific Results Postprint

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## Abstract

Since its successful lunar landing in December 2013, the Chang' e-3 lunar probe has remained on the Moon for over three years, establishing a world record for the longest operational duration on the lunar surface. Concurrently, the eight scientific payloads onboard the Chang' e-3 spacecraft have acquired a substantial volume of scientific exploration data. To advance the application and research of scientific data from the Chang' e-3 mission and strive to produce high-quality results expeditiously, the Chinese Academy of Sciences (CAS), prior to the mission's execution, assembled premier expertise nationwide to establish five core scientific application teams composed of scientists, technical personnel from scientific payload development units, and ground application system technical personnel responsible for scientific exploration data processing, and initiated a key deployment project titled "Scientific Application Research on Chang' e-3 Mission Exploration Data" . After more than two years, the core scientist team of the Chang' e-3 mission has achieved a series of innovative research findings in lunar topography and morphology, shallow subsurface geological structure, lunar-based astronomical observation, and Earth plasma observation.

## Full Text

## Abstract

The Chang' e-3 lunar spacecraft has remained on the Moon for over three years since its successful landing in December 2013, setting a world record for the longest operational duration on the lunar surface. During this time, the eight scientific payloads aboard the Chang' e-3 spacecraft have acquired vast amounts of scientific exploration data. To promote the application and research of this data and to ensure high-quality and timely results, the Chinese Academy of Sciences (CAS) assembled five core scientific application teams before the mission' s launch, drawing upon the nation' s top expertise. These teams comprised scientists, technical personnel from the payload development units, and ground application system engineers responsible for scientific data processing. CAS also established a key deployment project titled "Scientific Application Research on Chang' e-3 Mission Exploration Data." After more than two years of work, the Chang' e-3 core scientist teams have achieved a series of innovative research results in lunar topography, shallow subsurface geological structure, lunar-based astronomical observations, and Earth plasmasphere observations.

**Keywords:** Chang' e-3 mission, core scientist team, scientific achievements

## 1. Scientific Objectives and Payload Configuration of the Chang' e-3 Mission

The Chang' e-3 spacecraft, China' s first unmanned lunar soft-landing explorer, consists of a lander and a lunar rover (Yutu). Its successful landing and subsequent in-situ and roving exploration achieved the second strategic goal of China' s lunar exploration program— "orbit, land, return" —representing a major milestone in the nation' s aerospace development history.

In 2002, CAS led the formulation of scientific objectives for the second phase of the lunar exploration program. After project approval in 2008, CAS organized a specialized study on "Chang' e-3 Mission Payloads and Scientific Objectives," ultimately defining three primary scientific goals: (1) investigation of lunar surface morphology and geological structure, (2) survey of lunar surface material composition and utilizable resources, and (3) Earth plasmasphere detection and lunar-based optical astronomical observation. These three objectives are collectively summarized as "lunar measurement, sky observation, and Earth monitoring."

To accomplish these objectives, Chang' e-3 carried eight scientific payloads. The lander was equipped with a topography camera, landing camera, extreme ultraviolet camera, and lunar-based optical telescope, while the rover carried a panoramic camera, Lunar Penetrating Radar, Active Particle-Induced X-ray Spectrometer, and infrared imaging spectrometer. Among these, the lunar-based optical telescope, extreme ultraviolet camera, and Lunar Penetrating Radar were all internationally first-of-their-kind instruments for lunar scientific exploration.

The spacecraft was successfully launched from the Xichang Satellite Launch Center at 1:30 a.m. Beijing time on December 2, 2013, and soft-landed at 21:11 on December 14 in the Sinus Iridum region of the Moon' s Mare Imbrium at 19.51°W, 44.12°N, marking China' s first successful soft landing on an extraterrestrial celestial body. The lander and rover separated successfully on December 15, after which all eight scientific instruments were activated sequentially to acquire exploration data. The rover conducted traverses northward, eastward, southward, westward, and then northward again across the landing area. During the second lunar day, the rover experienced a malfunction, accumulating only about 114.8 meters of travel [Figure 1: see original paper]. The Active Particle-Induced X-ray Spectrometer examined only two points, and the infrared imaging spectrometer surveyed just four points. The extreme ultraviolet camera malfunctioned during the seventh lunar day in June 2014 and ceased observations after July 2014, having operated normally for approximately 230 hours over six months and acquired over 1,300 scientific images. Due to thermal control constraints, this payload could not achieve the expected round-the-clock observations (14 Earth days per lunar day) and could only operate during lunar morning and evening periods. Currently, the only instrument still functioning normally beyond its design lifetime is the lunar-based optical telescope installed on the lander.

From December 2, 2013, to June 30, 2016, Chang' e-3 conducted scientific exploration during 32 lunar days. By June 30, 2016, the Ground Research and Application System had archived a total of 7.07 TB of data from Chang' e-3, including 1.97 TB of raw data.

## 2. Exploring a New Management Model and Setting a Precedent

The successful implementation of the Chang' e-3 mission advanced China to a new stage in deep space exploration. As a primary implementing entity of China' s lunar exploration program, CAS took the lead in demonstrating and establishing scientific objectives, planning exploration tasks, and undertaking the development, construction, and operation of the Ground Research and Application System, payload subsystem, and VLBI (Very Long Baseline Interferometry) tracking subsystem. Concurrently, CAS pioneered an innovative management model for Chang' e-3' s scientific application research.

In September 2013, under the leadership of the Lunar Exploration Program Leading Group and Chief Commander System, and on the eve of the Chang' e-3 launch, CAS immediately organized a core scientist team for the Chang' e-3 mission. This team comprised nearly 100 experts and scholars from China University of Geosciences, Nanjing University, Shandong University (Weihai), Macau University of Science and Technology, Peking University, and relevant CAS institutes. Led by the Chief Scientist of the lunar application science program and organized by CAS' s General Office of Lunar and Deep-Space Exploration, the core team was structured around five research directions: "Lunar Topography and Geological Structure," "Lunar Surface Chemical Characteristics and Evolution," "Lunar Regional Geochemistry and Tectonic-Dynamic Evolution Modeling," "Earth Plasmasphere Characteristics and Solar Wind Interactions," and "Lunar-Based Optical Astronomy." Five core teams were formed, each integrating scientists, payload technical experts, and scientific data processing specialists. This "trinity" management model proved highly effective in advancing the scientific application of Chang' e-3 exploration data.

In October 2013, CAS allocated its own funds to establish the key deployment project "Scientific Application Research on Chang'e-3 Mission Exploration Data" to specifically support the core teams' research activities. After more than two years, the Chang' e-3 core scientist teams have achieved a series of innovative results in lunar topography, shallow subsurface structure, lunar-based astronomy, and Earth plasmasphere observations, publishing nearly 100 academic papers, including 62 SCI papers (31 international) and over 60 international conference papers.

## 3. Main Scientific Achievements of Chang' e-3

On October 15, 2015, the International Astronomical Union (IAU) officially approved the name "Guanghan Palace" for the region surrounding the Chang' e-3 landing site in northern Mare Imbrium (340.49°E, 44.12°N). Yutu' s arrival at "Guanghan Palace" marked the first lunar surface exploration mission conducted by human spacecraft in over 40 years since the Apollo program.

Using data from the four scientific payloads aboard the Yutu rover—panoramic camera, Lunar Penetrating Radar, visible-near infrared imaging spectrometer, and Active Particle-Induced X-ray Spectrometer—scientists conducted investigations of the landing area' s morphology, composition, and shallow crustal structure, obtaining first-hand in-situ exploration data that yielded numerous scientific results.

#### 3.1.2 Revealing Shallow Subsurface Structure and Geological Evolution History, Providing New Insights into Late-Stage Lunar Volcanic Activity and Geological Processes

On March 13, 2015, Professor Xiao Long from China University of Geosciences (Wuhan) and collaborators from Macau University of Science and Technology, CAS Institute of Electronics, and CAS National Astronomical Observatories, among others, utilized data from the Lunar Penetrating Radar and panoramic camera to conduct the first international analysis of the shallow structure characteristics and geological evolution history of the Chang' e-3 landing region. Their work revealed the geological features of the traverse area [FIGURE:2, FIGURE:3] and was published in *Science* under the title "Chang' e-3 Reveals Young, Multi-Layered Geological Structure in Northern Mare Imbrium."

On April 13, 2015, Researcher Lin Yangting from the CAS Institute of Geology and Geophysics, leading a Chang' e-3 core science team, utilized data from the four instruments aboard the Yutu rover to reveal for the first time internationally the volcanic evolution history of the Moon' s Mare Imbrium region. This research was featured as a cover article in *Proceedings of the National Academy of Sciences (PNAS)* [Figure 4: see original paper]. The results demonstrated that large-scale volcanic eruptions still occurred on the Moon as recently as approximately 2.5 billion years ago, possibly related to the region' s enrichment in radioactive elements. The lunar regolith thickness at the landing site was also significantly higher than previous estimates, providing important insights for understanding lunar evolution [Figure 5: see original paper]. The landing area is located in northern Mare Imbrium, where basaltic lava flows (dark black) are

2-3 billion years old, only about 10 kilometers from low-iron-titanium basalts (light gray) to the north.

#### 3.1.3 Discovery of a New Rock Type

The Planetary Science Team from Shandong University' s Institute of Space Sciences, in collaboration with seven domestic and international institutions, utilized data from the Active Particle-Induced X-ray Spectrometer and infrared imaging spectrometer [Figure 6: see original paper] to discover that rocks ejected from the "Ziwei" impact crater in the Chang' e-3 landing area represent a completely new type of lunar basalt [Figure 7: see original paper]. Published in *Nature Communications* on December 23, 2015, these findings attracted widespread attention in the academic community.

### 3.2 First International Implementation of Lunar-Based Near-Ultraviolet Sky Survey

Chang' e-3 achieved the first international lunar-based near-ultraviolet sky survey, filling partial gaps in the GALEX satellite survey coverage at low galactic latitudes [Figure 8: see original paper]. The lunar-based optical telescope remains the only scientific instrument on Chang' e-3 still operating normally. As of June 2016, it had conducted approximately 4,940 hours of sky survey observations, acquiring 233,000 image frames and yielding two major results.

First, in 2015, the lunar-based optical telescope research team led by Researcher Wei Jianyan from CAS National Astronomical Observatories published results in *Planetary and Space Science* establishing an upper limit for hydroxyl (water) density in the lunar exosphere (column density $<10^{11}$ cm $^{2}$, volume density not exceeding 10 cm $^{3}$). This measurement precision represents an improvement of two orders of magnitude over Hubble Space Telescope results and five orders of magnitude over India' s Chandrayaan-1, representing the most stringent constraints in this field to date.

Second, a major highlight of the lunar-based optical telescope involves the discovery of numerous new astronomical phenomena in variable star research. These include identifying a rare binary system undergoing rapid mass transfer, discovering a sample of binaries in slow mass-transfer evolutionary stages, finding a semi-detached close binary in a six-star system, and revealing the possibility that close binaries commonly exist in multiple-star systems.

### 3.3 Deciphering the Mysteries of Earth' s Plasmasphere

Earth' s plasmasphere is a toroidal region of cold plasma accumulation in the inner magnetosphere [Figure 9: see original paper], with primary components being ionospheric ions from below 60° north and south latitude trapped by Earth' s magnetic field. It is surrounded by the ring current and radiation belts [Figure 10: see original paper]. Chang' e-3 conducted the first international fixed-point, wide-field extreme ultraviolet observations of Earth' s plasmasphere from the lunar surface. From December 23, 2013, to June 12, 2014, the extreme ultraviolet camera installed on the Chang'e-3 lander accumulated approximately 230 hours of observations, acquiring over 1,300 images of Earth' s plasmasphere [Figure 11: see original paper].

Utilizing this data, the research team led by Researcher Wang Huaning from CAS National Astronomical Observatories achieved several breakthrough results. They discovered for the first time that Earth' s plasmasphere boundary develops bulges under the influence of magnetospheric substorms. As the coupling region between the magnetosphere and ionosphere, the plasmasphere' s structure is highly sensitive to geomagnetic activity (magnetic storms or substorms). During April 20-22, 2014, Chang' e-3' s extreme ultraviolet camera obtained large-scale and meridional perspective observations of Earth' s plasmasphere during a period when coronal mass ejections triggered multiple magnetospheric substorms. Combined with other space-based and ground-based observations, researchers investigated the plasmasphere' s response to substorms, revealing a close relationship between boundary bulges and substorm effects. These findings were published online in *Scientific Reports* on August 31, 2016.

Additionally, researchers confirmed that the plasmasphere's scale is inversely correlated with geomagnetic activity intensity, concluding that its spatial structure is constrained and controlled by Earth' s magnetic and electric fields. Analysis of all Chang'e-3 observations clearly validates this inverse relationship. Extreme ultraviolet camera images demonstrate that during quiet magnetospheric periods, the plasmasphere can extend to 6.5 Earth radii, while during the strongest observed activity (February 21, 2014), the plasmapause contracted to 3.5 Earth radii. These results are consistent with empirical plasmasphere models and in-situ satellite measurements.

Through CAS' s active and effective organizational management and strong support, the application and research of Chang' e-3 scientific exploration data have achieved the goals of "rapid, abundant, and high-quality results." The mission' s rich scientific achievements have gained recognition and high praise from international peers, advancing China' s lunar science research to a new level. Moreover, the lunar-based optical telescope continues its sky survey, and other scientific research activities remain ongoing. As in-depth research continues, more outstanding results will undoubtedly emerge. Importantly, the management model pioneered for Chang' e-3' s scientific application and research will provide an excellent precedent for future lunar and deep-space exploration missions in China.

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**Preliminary Scientific Achievements of Chang' e-3 Mission**

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**Abstract:** Chang' e-3 spacecraft landed on the Moon on 14 December 2013, and set a world record for the longest working hours on the surface of the moon. The eight scientific payloads of the Chang' e-3 have achieved a large amount of scientific exploration data. In order to promote the application and research of these exploration data, and strive for sound and quick results, Chinese Academy of Sciences conducted the key deployment project of application research on the scientific data from CE-3 before launch. Five core teams of scientists consisted of scientists, scientific instruments, and Ground Research and Application System technical personnel. The five core teams have achieved a series of innovative research results in lunar topography, regolith structure, lunar based astronomical observation, and earth plasma observation in 2 years.

**Keywords:** Chang' e-3 mission, the core team of scientists, scientific achievements

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*Note: Figure translations are in progress. See original paper for figures.*